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Research Paper

Traffic Intersections Noise Levels and Daily Noise Exposure in Chandrapur City, Central India

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Abstract
Noise level monitoring was carried out at nine important traffic intersections of the Chandrapur city to ascertain noise levels and daily noise exposure. A pre-calibrated mini sound level meter was used for noise measurement. Observations were recorded for 24 hours and noise level during the day, night and for 24-hours was computed. Maximum noise level during daytime was 84.27 dB(A) at Bangali camp square; whereas, minimum 79.23 dB(A) at Priyadarshani square. In case of nighttime maximum 85.90 dB(A) was at Warora naka square and minimum 70.06 dB(A) at the Jatpura gate. Minimum noise level during 24-hours was at Bagla square 84.34 dB(A) and maximum 91.14 dB(A) at Warora naka square. Noise level during day and night were above the Indian noise standard for the commercial area. The Bangali camp square was identified as the most ear-splitting square during daytime and Warora naka square at nighttime and for 24-hours also. Peak noise was recorded from 10.00 am to 11.00 am and 3.00 pm to 7.00 pm. Vehicular noise, horns, and improper road design contributed significantly to noise levels at traffic intersections. Daily noise exposure analysis by Health and Safety Executive, UK software revealed Bangali camp square and Ramnagar police station square's daily noise exposure for 0.25 hour was maximum 70 LEP,d and minimum at Gandhi square and Bagla square 65 LEP,d. Noise levels indicated no immediate effect for hearing loss. Control measures for reduction of noise levels at traffic intersections have also been proposed.

Keywords
Chandrapur, Noise exposure, Noise pollution, Traffic intersection, Traffic noise

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1. INTRODUCTION

Noise can be defined as the sound which exceeds the acceptable level and creates annoyance. The major sources of noise are industrial, vehicular, and community. Out of these three, the source that affects the most is the traffic noise. Almost 70% of the noise is contributed by vehicular noise. The recognition of vehicular traffic noise is one of the main sources of environmental pollution. Due to increase in population, urbanization and rapid industrialization, there is a significant increase in vehicular number in urban areas which had lead to traffic problems. Traffic noise from highways creates problems for surrounding areas, especially when there is heavy traffic volume and speed (Karibasappa et al., 2015).

Noise pollution is one of the important issues of environmental pollution in metropolitan areas. Being one of the most harmful agents, many countries had introduced noise standards for vehicles and other legislation to reduce road traffic noise (Ross and Wolde, 2001). Motor vehicles are the main source of noise pollution in the urban environment. Therefore, the urban masses are exposed to high noise level due to traffic on road, at the workplace as well as in transit. Noise pollution is quantitatively measured in term of equivalent noise level (Leq). The total acoustical energy released to the surrounding environment by the traffic distributed unevenly over the different frequency octave within the audible range from 20 to 20,000 Hz (Mohan et al., 2000).

Urban areas are majorly under the cover of traffic noise. Traffic noise produces disturbance and adverse effects on individuals as compared to other sources of noise. According to Central Pollution Control Board road traffic contributes around 55% of total noise contamination. In urban areas, engines and fumes, arrangement of automobile, litter trucks, transports and two-wheelers are the contributors of traffic noise (Sankhat et al., 2017).

Road traffic noise in Europe accounts for more than 90% of unacceptable noise levels (daytime LAeq > 65 dB(A)) (Filip et al., 2002). In India, traffic mix is usually heterogeneous and conditions of traffic congestions and interruption

Table 1. Traffic Intersection Details

Traffic Intersection	No. of roads at the intersection	Fleet composition	Traffic light presence	Intersection typology	Traffic volume	Traffic flow typology
Janata college square	Four	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (trucks, buses)	Yes	Traffic light controlled	Heavy	Pulsed continuous flow
Warora naka square	Four	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (trucks, buses)	Yes	Planar	Heavy	Fluid continuous flow
Ramnagar police station square	Four	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (trucks, buses)	Yes	Traffic light with a roundabout	Heavy	Pulsed continuous flow
Priyadarshani square	Four	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (trucks, buses)	Yes	Traffic light controlled	Heavy	Pulsed continuous flow
Bangali camp square	Four	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (trucks, buses)	Yes	Traffic light with a roundabout	Heavy	Pulsed continuous flow
Gandhi square	Three	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (buses)	No	Planar	Medium	Pulsed continuous flow
Girnar square	Three	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (buses)	Yes	Traffic light controlled	Medium	Pulsed continuous flow
Jatpura gate square	Three	Two-wheelers (moped); Four wheelers (cars); Heavy vehicles (buses)	No	Planar	Medium	Pulsed decelerated flow
Bagla square	Four	Two-wheelers (moped); Four wheelers (cars);	No	Planar	Light	Pulsed continuous flow

are very frequent and further heavy traffic volumes, higher speeds, and a greater number of trucks and buses also contribute the loudness of traffic noise. Inappropriate stoppage of buses at locations rather than designated one also contributes traffic congestions on roads. Besides, as the roads are narrower and different types of vehicles are not plying separately on the road lanes create declaration and acceleration noises as vehicles approach and depart from each other city (Rajkumara and Gowada, 2009).

After carrying out an online and published literature review for noise levels at traffic intersections and exposure analysis for the Chandrapur city, it was found that no such study was carried out previously. Hence, a gap was identified. To fill this knowledge gap by generating a new one in this subject domain this study was proposed to carry out. The main objective of the study was to assess existing noise levels in different traffic intersections of the Chandrapur city. Furthermore, noise level exposure analysis to individual and traffic policemen/women who were deployed to manage traffic flow at these intersections.

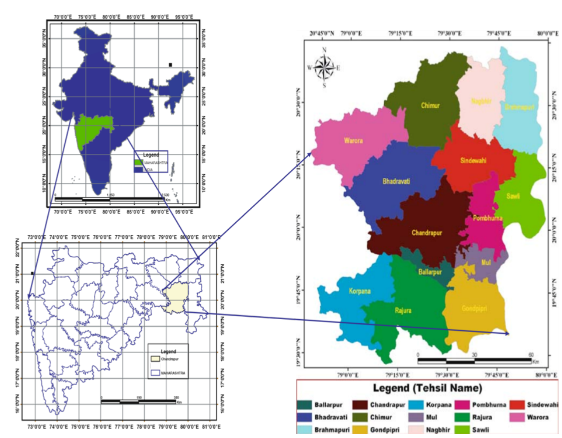

Figure 1. Chandrapur district map (Satapathy et al., 2009)

Table 2. Noise Levels at Traffic Intersections

Time (Hour)	Janata college square	Warora naka square	Ramnagar police station square	Priyadarshani square	Bangali camp square	Gandhi square	Girnar square	Jatpura gate square	Bagla square
	Noise level in dB(A)								
7.00 am	72.1	72.7	74.3	72.5	80.7	69	71.4	68.8	71.9
8.00 am	71	73.2	76.9	71.1	71.9	71.5	70.1	70.5	73.2
9.00 am	73.8	73.4	68.4	71.3	74.1	70.5	71.9	70.4	73.8
10.00 am	77.6	74.3	77.3	74.2	79.2	74.9	76.2	76.9	76.7
11.00 am	75.2	79.7	72.4	71.9	79.3	71.8	79	75	69.3
12.00 pm	66.1	71.5	73.2	72	76.8	70.2	68.4	77.3	69.4
1.00 pm	66.1	68	73.4	72.3	65.6	72.4	68.9	71	69.9
2.00 pm	69	70.3	77.7	69.8	68.5	67.9	64.5	68.8	68.1
3.00 pm	72.5	74.3	76.6	61.7	74.5	69.9	71.2	69.1	75.3
4.00 pm	68.9	71.1	79.3	51.2	69.2	68.3	70.2	69	59.1
5.00 pm	66.4	65.2	72.8	52.4	59.5	61.3	65.2	74.6	58.2
6.00 pm	66.5	66.6	59.4	59.4	60.5	58.4	60	70	60.3
7.00 pm	63.3	61.5	58.7	59.8	61.6	59.3	61.8	69.7	58.1
8.00 pm	63.5	62.9	56.6	59.8	63.8	63.2	62.4	71	65.1
9.00 pm	57.4	59.6	58.9	61.2	58.8	51.9	54.6	70.8	59.6
10.00 pm	54.5	55.4	63.9	64.1	55.4	54.3	52.1	66.9	57.5
11.00 pm	59.3	58.4	55.6	65.7	56.9	59.3	55.6	58.7	61.1
12.00 am	59.6	57.7	54.2	70.9	58.6	71.3	57.2	60	56.6
1.00 am	68	69.5	62.3	74.2	67.8	65.8	70	60.7	61.5
2.00 am	69.9	71	67.4	66.8	65.9	68	67.9	55.9	66.6
3.00 am	74.3	77.2	71.4	71.3	65.2	75.9	72.5	48.8	71.4
4.00 am	77.2	76.1	69.5	74.5	72.4	75.2	72.5	47.5	74.1
5.00 am	70.1	72.2	75.4	69.5	73.6	63.5.	60.5	60.4	67.8
6.00 am	76.2	88.4	75.5	76.1	83.3	74.8	75.9	70.8	72.4
Min.	54.5 10.00 pm	55.4 10.00 pm	54.2 12.00 pm	51.2 4.00 pm	55.4 10.00 pm	51.9 9.00 pm	52.1 10.00 pm	47.5 4.00 pm	56.6 12.00 pm
Max.	77.6 10.00 am	88.4 6.00 am	79.3 4.00 am	76.1 6.00 am	83.3 6.00 am	75.9 3.00 am	79 11.00 am	77.3 12.00 am	76.7 10.00 am
Average	68.27	69.59	68.79	67.23	68.46	67.17	66.66	66.77	66.54
Std. dev.	6.31	7.69	8.01	7	8.15	6.83	7.26	8.01	6.5

Min. - Minimum, Max. - Maximum, Std. dev. - Standard deviation (±).

Table 3. Noise Levels During Day, Night And 24-Hours at Traffic Intersections

Traffic intersection	Noise level during daytime (Ld) dB(A)	Noise level during nighttime (Ln) dB(A)	Noise level during 24-hours (Ldn) dB(A)
Janata college square	80.94	78.84	85.87
Warora naka square	82.18	85.9	91.14
Ramnagar police station square	84.06	76.87	87.3
Priyadarshani square	79.23	78.23	84.93
Bangali camp square	84.27	81.03	88.85
Gandhi square	79.26	77.85	84.73
Girnar square	81.17	76.42	85.14
Jatpura gate	82.32	70.06	84.77
Bagla square	80.56	75.27	84.34
Minimum	79.23	70.06	84.34
Maximum	84.27	85.9	91.14
Average	81.55	77.83	86.34
Std. dev.	1.83	4.27	2.31

Std. dev. - Standard deviation (±).

Table 4. National Ambient Air Quality Standards in Respect of Noise

Area Code	Category of Area/Zone	Limit in dB(A) Leq* Daytime	Night time
A	Industrial Zone	75	70
B	Commercial Zone	65	55
C	Residential Zone	55	45
D	Silence Zone	50	40

Note: 1. Daytime shall mean from 6.00 a.m. to 10.00 p.m. 2. Nighttime shall mean from 10.00 p.m. to 6.00 a.m. 3. Silence zone is defined as an area comprising not less than 100 meters around Hospitals, Educational Institutions, and courts. The silence zones are zones which are declared as such by the competent authority. 4. Mixed categories of areas may be declared as one of the four abovementioned categories by the Component Authority. *dB(A) Leq denotes the time-weighted average of the level of sound in decibels on scale A which is related to human hearing "A", in dB(A) Leq, denotes the frequency weighting in the measurement of noise and corresponds to frequency response characteristics of the human ear Leq: It is an energy mean of the noise level over a specified period

Figure 2. Sampling locations from the study area. (a) Janata college, (b) Warora naka, (c) Ramnagar police station, (d) Bangali camp and (e) Jatpura gate

Table 5. Daily Noise Exposure at Traffic Intersections

Traffic intersection	Noise level during daytime (Ld) dB(A)	Duration of exposure to traffic noise													
		0.25 hour		1 hour		2 hours		4 hours		6 hours		8 hours		10 hours	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Janata college square	80.94	65	1	72	5	75	10	78	20	80	29	81	39	82	49
Warora naka square	82.18	68	2	73	7	76	13	79	26	81	39	82	52	83	65
Ramnagar police station square	84.06	70	3	75	10	78	20	81	40	83	60	84	81	85	101
Priyadarshani square	79.23	65	1	70	3	73	7	76	13	78	20	79	26	80	33
Bangali camp square	84.27	70	3	75	11	78	21	81	42	83	63	84	85	85	106
Gandhi square	79.26	65	1	70	3	73	7	76	13	78	20	79	27	80	33
Girnar square	81.17	65	1	72	5	75	10	78	21	80	31	81	41	82	52
Jatpura gate	82.32	68	2	73	7	76	13	79	27	81	40	82	54	83	67
Bagla square	80.56	65	1	71	4	75	9	78	18	79	27	81	36	82	45
Minimum	79.23	65	1	70	3	73	7	76	13	78	20	79	27	80	33
Maximum	84.27	70	3	75	11	78	21	81	42	83	63	84	85	85	106

A - Daily noise exposure (LEP,d), B - Exposure point's (jobs/tasks).

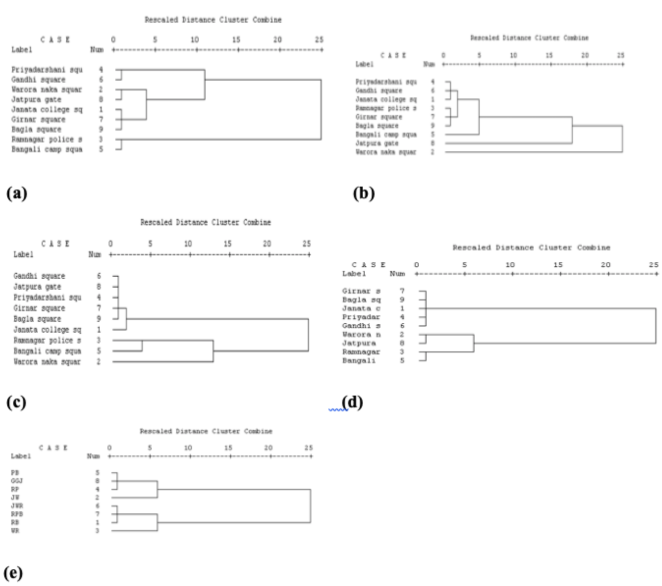

Figure 3. Cluster analysis. (a) Daytime, (b) Nighttime, (c) For 24-hours, (d) Noise exposure at a traffic intersection (0.25 hour) and (e) At combinations of traffic intersections

1.1 Study Area

Chandrapur formerly 'Chanda' (19.57º N latitude and 79.18º E longitude) is a city and municipal corporation in Chandrapur district of Maharashtra state of India (Figure 1). The city is situated at an altitude of 189.90 m above sea level and has a geographical area of 70.02 sq km. The North-South length of the city is about 10.6 km, while the East-West is about 7.6 km. In a 2011 state cabinet decision, Chandrapur Municipal Corporation was elevated to D grade Municipal Corporation. The city has 67 wards and divided into 3 zones. According to the 2011 Census of India, the city had a population of 375,000.

The Chandrapur city is a 13-century historic fort city which is divided into two, the old city which is situated inside the fort and new outside it. The old city is haphazardly settled with narrow by lanes and congested traffic intersections. The new city is systematically settled with proper town planning. The total road length of the city is 495.36 km. Different types of roads in the city include concrete road 56.58 km, tar road 188.16 km, pedestrian road 140.02 km and unpaved road 110.60 km. National Highway NH 930 (four lanes with divider) passes from North to East

Table 6. Noise exposure at combinations of traffic intersections

Traffic intersection combinations (Abbreviation)	Duration of noise exposure at each intersection (Hour)	Daily noise exposure (LEP,d)	Exposure point's (jobs/tasks)
Ramnagar police station square and Bangali camp square (RB)	0.25	73	6
Janata college square and Warora naka square (JW)	0.25	70	3
Warora naka square and Ramnagar police station square (WR)	0.25	72	5
Ramnagar police station square and Priyadarshani square (RP)	0.25	71	4
Priyadarshani square and Bangali camp square (PB)	0.25	71	4
Janata college square; Warora naka square and Ramnagar police station square (JWR)	0.25	73	6
Ramnagar police station square; Priyadarshani square and Bangali camp square (RPB)	0.25	73	7
Gandhi square; Girnar square and Jatpura gate square (GGJ)	0.25	71	4

Table 7. Damage risk criteria for hearing loss Occupational Safety and Health Administration (OSHA)

Maximum Allowable Duration Per Day, Hour	Noise Level dB (A) (Slow Response)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

direction of the city connecting Warora to Chandrapur and further Chandrapur to Mul. State Highway SH 264 connects Chandrapur to Ballarpur and Major State Highway MSH 6 connecting Chandrapur to Ghugus. Presently, there is no outer ring road for the city as a result of which heavy vehicles (four wheelers and long vehicles) passes from this National Highway NH 930 through the city. To cater to the needs of inhabitants of the city limited public transport system is operated by Chandrapur Municipal Corporation from Anchaleshwar gate to Urjanagar. In addition, private bus operators (intercity) also provide bus service from various parts of the city. State bus terminal connects the city to various parts of Maharashtra and adjoining Telangana state. The city has two railway stations. Chandrapur railway station is situated on New Delhi-Chennai route and Chanda Fort station on Bangalore-Gorakhpur route. Both stations connect the city to major parts of India.

The city has two main roads (one way only) namely,

Table 8. Pearson Correlation Coefficient Among Various Variables

Variable	Person correlation coefficient (r)	Sig. (1-tailed)	Detail
Number of roads merging at intersections and noise level during 24-hours (Ldn)	r = -0.473	0.099	
Traffic light presence at intersections and noise level during 24-hours (Ldn)	r = -0.559	0.059	
Traffic volume (Heavy, medium, light) at intersections and noise level during 24-hours (Ldn)	r = -0.623*	0.037	*Correlation is significant at the 0.05 level (1-tailed)
Noise level during daytime (Ld) and noise level during nighttime (Ln)	r = 0.110	0.389	
Noise level during daytime (Ld) and noise level during 24-hours (Ldn)	r = 0.804**	0.004	**Correlation is s ignificant at the 0.01 level (1-tailed)
Noise level during nighttime (Ld) and noise level during 24-hours (Ldn)	r = 0.611*	0.04	*Correlation is significant at the 0.05 level (1-tailed)
Noise level during daytime (Ld) and daily noise exposure (LEP,d) for 0.25 hour	r = 0.930**	0	**Correlation is s ignificant at the 0.01 level (1-tailed)

Table 9. Correlation Matrix For Day, Night and 24-Hours Noise Level

		Day	Night	24-Hours
Correlation	Day	1	0.11	0.611
	Night	0.11	1	0.804
	24-Hours	0.611	0.804	1
Sig. (1-tailed)	Day		0.389	0.04
	Night	0.389		0.004
	24-Hours	0.04	0.004	

Mahatma Gandhi road and Kasturba road. Along both the sides of these one-way number of shops and other commercial activities are carried out. Footpaths are present however are occupied by shopkeepers for Sunday market near Gandhi square. Limited parking facilities are made available for two-wheelers and auto-rickshaws at selected locations along the roadside. These roads carry the entire city traffic from Pathanpura gate in the remote South end to the North to Jatpura gate and onwards to civil lines and government offices complex. The city traffic further disperses to Warora, Nagpur and towards North to Chandrapur Super Thermal Power Station, coal mines and to Tadoba Andhari Tiger Reserve. The traffic towards the North further leads towards East to Mul and Gadchiroli–the other important neighboring urban centers. Jatpura gate which serves as an entrance point to the city creates daily traffic congestion during afternoon hours. Vehicular demography as of 31st March 2011 of the city includes motorcycles 139343, scooters 401613, mopeds 44690, motor cars and jeeps 21466, auto-rickshaws

Table 10. Principal Component Analysis

Component	Initial Eigen values			Extraction Sums of Squared Loadings			Componenta	
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	1	
1	1.11	55.488	55.488	1.11	55.488	55.488	Day	0.745
2	0.89	44.512	100				Night	0.745

Extraction method: Principal component analysis, One component extracted.

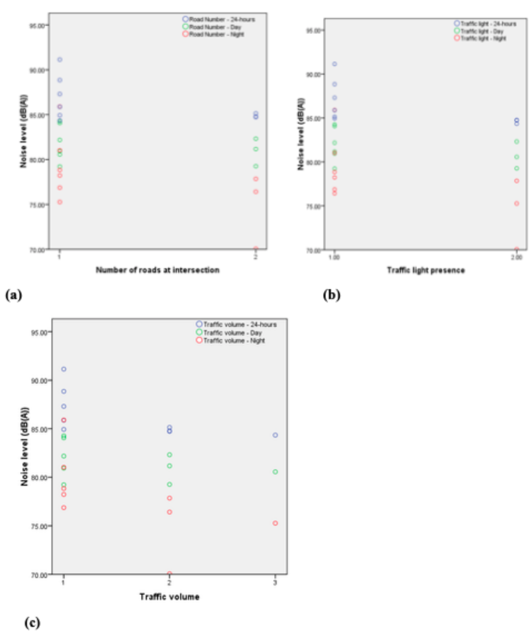

Figure 4. Scatter plots. (a) Number of roads merging at intersections versus noise levels, (b) Traffic light presence or absence versus noise levels and (c) Traffic volume versus noise levels

6852, trucks, lorries and tankers 7961 and tractors and trailers 12654 (Motor Transport Statistics of Maharashtra, 2010-2011). The vehicular growth rate in the Chandrapur region was 8.25% during 2012-13 to 2013-14; 8.30% from 2013-14 to 2014-15 and 8.69% for the period of 2014-15 to 2015-16.

2. EXPERIMENTAL SECTION

2.1 Noise sampling and analysis

The Chandrapur city has number of traffic intersections. Out of these intersections, nine were selected for the study by stratified sampling and on the basis of design of intersections. Janata college square (Figure 2a) is a traffic light controlled intersection; whereas, Warora naka square (Figure 2b) with a planar type intersection typology. Ramnagar police station square (Figure 2c) and Bangali camp square (Figure 2d) are traffic light controlled with a roundabout. Ramnagar police station traffic intersection is comparatively wider than Bangali camp square. Jatpura gate traffic intersection (Figure 2e) with a narrow entry through a gate serves as an entrance for the old Chandrapur city. At this intersection traffic volume was medium with pulsed decelerating flow typology. Traffic intersections identified for the study along with details such as numbers of roads merging at the intersection, fleet composition along with presence of traffic light, volume and flow typology is presented in Table 1. From the table, it can be seen that at all traffic intersections two wheelers, four wheelers, and heavy vehicles were dominating. It can be further observed, 66.66% (n=6) traffic intersections had four roads merging; whereas, 33.33% (n=3) had three roads. It can also be pointed out that traffic intersections in the old city had three roads merging, on the other hand, those in the periphery and outskirt of the city had four roads.

Ambient noise levels at various traffic intersections of the city were monitored in 2017. Sound Pressure Level (SPL) measurements were recorded with a precision mini sound level meter (Center 325 Sound Level Meter IEC 651 Type II, Made in Taiwan) which was calibrated before measurements were carried out. Noise levels were recorded in “A” weighting. Measurements were recorded at receiver’s position 1.2 m above ground level and away from any reflecting object. Noise monitoring was carried out for 24 hours day and night so as to compare the difference in noise level and compute noise level during daytime (Ld), nighttime (Ln) and during 24-hours (Ldn). A noise rating method developed by the US Environmental Protection Agency (US EPA) for community noise from all sources was used. It is similar to 24 hours equivalent sound levels except that during nighttime a 10 dB(A) correction is added to the instantaneous sound levels before computing 24 hours average. The nighttime penalty is added to account for the fact that noise at night when people are trying to sleep is judged more annoying than the same noise during the daytime. Ldn for a given location is calculated from hourly equivalent sound levels (Leq) using the following formula:

$$Ldn = 10log1/24[15(10Ld/10) + 9(10(Ln + 10)/10)] \quad (1)$$

Where, Ld - equivalent noise level during daytime (0600 to 2200 hours) ; Ln - equivalent noise level during nighttime (2200 to 0600 hours).

2.2 Noise Exposure

Noise exposure calculator developed by the Health and Safety Executive (HSE), UK was used to calculate noise exposure to traffic policeman/women deployed at traffic intersections and commuters on road. The exposure calculator calculates exposure point's job per task and exposure points per hour by considering noise level and exposure duration in hours. These exposure points can be used to prioritize noise control. The highest exposure points make the greatest contributions to daily noise exposure. Thus, controlling these noise exposures will have greatest effect on daily noise exposure.

Commuters spend variable time on street and at traffic intersections. An attempt was also carried out in this study to calculate noise exposure at two and three traffic intersections combinations for varying duration (0.25-10 hours). In addition, a questionnaire-based field survey was also carried out for assessing noise exposure to traffic personnel and shopkeepers of the city.

2.3 Statistical Analysis

The data on noise level, number of roads merging at intersections, presence of traffic light, traffic volume, noise level during daytime-nighttime, noise level during daytime-24-hours noise level, noise level during night-24-hours noise level and daily noise exposure were statistically analyzed with the help of Pearson correlation coefficient (r) by using SPSS to understand the strength of the relationship between these variables. Furthermore, cluster analysis was applied to identify traffic intersections with similar or comparable noise level during day, night and 24-hours. Cluster analysis was formulated according to Ward algorithmic method. Outcomes were shown in dendrograms, which illustrated hierarchical arrangement of resulting clusters, and values of the distance between clusters (square Euclidean distance) were represented. A correlation matrix was used to identify the relationship between day, night and 24-hours noise levels at various intersections (Richard and Gregory, 1985). Principal component analysis (PCA) was used to infer the traffic noise source (anthropogenic or vehicular).

3. RESULTS AND DISCUSSION

3.1 Noise Levels at Traffic Intersections

Hourly noise level at traffic intersections of the city at nine sampling locations is presented in Table 2. From the observations reported in the table it can be seen that at Janata college square minimum noise level was 54.5 dB(A) (10.00 pm); whereas, maximum of 77.6 dB(A) (10.00 am) and an average of 68.27 dB(A). In case of Warora naka square, minimum, maximum and average noise levels were 55.4 dB(A) (10.00 pm), 88.4 dB(A) (6.00 am) and 69.59 dB(A) respectively. At Ramnagar police station square 54.2 dB(A) (12.00 pm), 79.3 dB(A) (4.00 pm) and 68.79 dB(A) were minimum, maximum and average noise levels respectively. The minimum noise level of 51.2 dB(A) (4.00 pm), maximum of 76.1 dB(A) (6.00 am) and average 67.23 dB(A) were recorded at Priyadarshani square. Bangali camp square had minimum, maximum and average noise levels as 55.4 dB(A) (10.00 pm), 83.3 dB(A) (6.00 am) and 68.46 dB(A) respectively. At Gandhi square, it was recorded as 51.9 dB(A) (9.00 pm) as minimum, 75.9 dB(A) (3.00 am) as maximum and 67.17 dB(A) as average noise level. At Girnar square minimum, maximum and average noise levels were 52.1 dB(A) (10.00 pm), 79.0 dB(A) (11.00 pm) and 66.66 dB(A) respectively. Noise level at Jatpura gate was monitored as 47.5 dB(A) (4.00 am) as minimum, 77.3 dB(A) (12.00 am) as maximum and average of 66.77 dB(A). At Bagla square minimum, maximum and average noise levels were 56.6 dB(A) (12.00 pm), 76.7 dB(A) (10.00 am) and 66.54 dB(A) respectively.

Among all these sampling locations, the minimum noise level was recorded at Jatpura gate 47.5 dB(A) (4.00 am); whereas, Warora naka square had the maximum noise level 88.4 dB(A) (6.00 am). The maximum average noise level was 69.59 dB(A) at Warora naka square. The minimum standard deviation was at Janata college square ±6.31 dB(A) which indicates there was less variation in noise level during 24-hours. On the contrary, the maximum standard deviation ±8.15 dB(A) was recorded at Bangali camp square which indicates variation in noise level during 24-hours.

Peak noise hours at these traffic intersections were recorded from 10.00 am to 11.00 am in morning; whereas, from 3.00 pm to 7.00 pm in afternoon and evening. Peak noise duration in morning coincides with opening of offices, schools, and commencement of other activities. Afternoon and evening peak noise duration can be assigned to commercial activities, closing of offices, schools, beginning of local market activities etc.

Noise levels during day, night and 24-hours at traffic intersections were calculated with the help of formula developed by US EPA (Formula 1) is presented in Table 3.

From the table it can be observed that, minimum daytime (Ld) noise level was 79.23 dB(A) at Priyadarshani square and maximum at Bangali camp square 84.27 dB(A). At Bangali camp square heavy vehicles plying on the street may have contributed to this elevated noise level. Minimum noise level during nighttime (Ln) was at Jatpura gate 70.06 dB(A); whereas, maximum 85.90 dB(A) at Warora naka square. At this sampling location, heavy traffic in addition to students activities from nearby education institutions may have contributed to enhanced noise level. The sound waves generated by vehicles at the intersection propagate in ambient atmosphere. Out of which few sound waves strike to the bottom of the flyover and reflect back again on commuters. This phenomenon may have resulted in an increase in noise level. Furthermore, no traffic signal and traffic policemen to monitor the flow of vehicles may have contributed to these observations. Minimum noise level during 24-hours (Ldn) was recorded at Bagla square 84.34 dB(A) and maximum at Warora naka square 91.14 dB(A). Bagla square is located in the outskirt of the city with sporadic population and wide roads. Socio-economic conditions of the inhabitants in the adjoining areas restrict them to use two-wheelers mostly as a result of which four wheelers number was limited. These factors may have resulted in a minimum noise level for 24 hours (Ldn).

Maximum noise level difference [7.19 dB(A)] during day (Ld) and night (Ldn) was recorded at Ramnagar police station square. Bangali camp square was identified as the most ear-splitting square during daytime; whereas, Warora naka square during nighttime and 24-hours also. On comparison of noise level during daytime and nighttime with National Ambient Air Quality Standards (NAAQS) with respect to noise for the commercial zone (Table 4), it was observed that at all sampling locations the noise level exceed the limit during day and nighttime both.

3.2 Daily Noise Exposure

Daily noise exposure at traffic intersections is presented in Table 5. A commuter spends variable time at different traffic intersections; whereas, traffic policemen and women deployed at these intersections to monitor traffic flow had working hours for 8 to 10 hours per day. Daily noise exposure during daytime (Ld) noise level to commuters and police personnel revealed, Bangali camp square and Ramnagar police station square noise exposure for 0.25 hour were maximum 70 LEP,d. Both these intersections were one of the largest ones with heavy traffic flow throughout day and night and are the part of National Highway NH 930 and State Highway SH 264. In case of eight hours of traffic noise exposure, Ramnagar police station square and Bangali camp square had the maximum daily noise exposure of 84 LEP,d. This trend remained continued for 10-hours exposure period also (85 LEP,d). The minimum daily noise exposure was at Gandhi square and closely followed by Bagla square with daily noise exposure of 65 LEP,d for 0.25 hour. Both these squares were one of the smallest squares and located in a congested area with limited traffic flow devoid of heavy vehicles and traffic light. On comparison of noise exposure during daytime with Occupational Safety & Health Administration (OSHA) standards (Table 7), it can be arrived at that there was no immediate damage risk for hearing loss on inhabitants of the city and on traffic personal deployed at traffic intersections. Temporary deafness, stress, auditory fatigue, annoyance etc. can cause due to exposure to these noise levels.

Results of noise exposure at combinations of traffic intersections are reported in Table 6. From the table, it can be observed that Ramnagar police station square and Bangali camp square together had daily noise exposure during daytime as 73 LEP,d. In case of three traffic intersection combinations, Ramnagar police station, Priyadarshani square and Bangali camp square had daily noise exposure during daytime as 73 LEP,d which was closely followed by a combination of Janata college square, Warora naka square and Ramnagar police station square 73 $L_{EP,d}$.

A noise exposure analysis through a questionnaire was also carried out. For this field based survey nine traffic personnel were identified who were working for more than five years and had no health-related issues. All respondent reported irritation and disturbance due to traffic noise. Heterogeneous sources such as two and four-wheelers were identified as noise source (100%); whereas, 40% as national highway and $\sim$ 16% as railway. Maximum noise exposure time was in afternoon (53.30%) followed by morning (33.30%) and minimum during evening (13.30%). Traffic noise was reported on all weekdays (86.60%); whereas, 13.30% stated Sunday had more traffic noise. Average noise exposure was for 12 hours a day (90%); whereas, remaining had reported it for $>$ 12 hours. Effects of noise exposure as reported by police personnel include annoyance, sleep disturbance, stress and lack of concentration. No personal protective equipment was used to protect from traffic noise exposure.

Furthermore, noise exposure assessment was also carried out on shopkeepers (n=25) which were exposed to traffic noise while working in their shops. All respondent reported two and four wheelers as a traffic noise source. Daytime noise exposure was reported by $\sim$ 83%; whereas, $\sim$ 16% reported it during nighttime. Annoyance and lack of concentration were effects reported by all subject population; whereas, sleep disturbance and stress by $\sim$ 66% and $\sim$ 53% respectively. No personal protective equipment was used by shopkeepers and awareness level regarding noise and other related standards were absent.

3.3 Pearson Correlation Coefficient

In order to quantitatively analyzed and confirm the relationship between 24-hours noise levels and other variables, Pearson correlation coefficient analysis was applied to the data (Table 8). There was a statistically significant positive correlation between noise level during daytime (Ld) and noise level during 24-hours (Ldn) ($p<0.01$); noise level during nighttime (Ln) and noise level during 24-hours (Ldn) ($p<0.05$) and noise level during daytime (Ld) and daily noise exposure (LEP,d) for 0.25 hour ($p<0.01$). In the case of traffic volume and noise level during 24-hours (Ldn), a negative correlation was observed ($p<0.05$). Other variables such as number of roads merging at traffic intersection and the presence of traffic light were not correlated with noise level during 24-hours (Ldn). Noise level during daytime (Ld) and nighttime (Ln) were not correlated with each other.

3.4 Cluster Analysis

Figure 3a depicts four clusters for daytime (Ld) noise levels. Cluster 1 depicts Priyadarshani square and Gandhi square traffic intersections. Both these intersections were of had different characteristics with reference to the presence of traffic light; however, had comparable noise levels. Warora naka square and Jatpura square forms the cluster 2. At both these intersections, traffic lights were not present as a result of which fluid continuous flow and pulsed continuous flow traffic typology respectively were there, which resulted in vehicles on continuous move. Cluster 4, Ramnagar police station square and Bangali camp square, represents the noisiest intersections during daytime. At both these intersections, traffic light with roundabout was present. Cluster analysis of noise levels during nighttime (Ln) is depicted in Figure 3b whereas, for 24-hours noise levels (Ldn) in Figure 3c both shows five clusters. This cluster analysis suggested that variables such as roundabout and absence or presence of traffic light had contributed to noise level at a traffic intersection at an individual level.

Cluster analysis of daily noise exposure at an individual traffic intersection for daytime (Ld) for 0.25 hour is depicted in Figure 3d. It can be seen that three clusters are there. The major cluster comprises five traffic intersections with daily noise exposure of 65 LEP,d. Maximum daily noise exposure was at Ramnagar police station square and Bangali camp square with similar traffic intersection characteristics such as a roundabout, presence of traffic light and heavy traffic volume (trucks and buses).

Cluster analysis of daily noise exposure for 0.25 hour at combinations of traffic intersections is presented in Figure 3e. Four clusters were observed for these combinations. In two clusters (six traffic intersections combinations) daily noise exposure was comparable which indicates higher daily noise exposure at a combination of traffic intersections as compared with individual traffic intersection (Figure 3d). Similar observations were also recorded for exposure points (job per tasks). Thus, exposure at different traffic intersections may be harmful as compared with a signal traffic intersection.

3.5 Correlation Matrix and Principal Component Analysis

Correlation matrix between day, night and 24-hours noise level is presented in Table 9. From this table, it can be seen that nighttime noise level had a strong correlation ($r=0.804$) with 24-hours noise level as compared with daytime ($r=0.611$). In the Principal component analysis (Table 10), noise levels were grouped into two models, which account for 100% of all the data variation. In the rotated component matrix, the first principal component (variance of 55.48%) was for daytime while second principal component (variance of 44.52%) was for nighttime. The results indicate that daytime noise level contribution was higher as compared with nighttime.

3.6 Scatter Plot

A scatter plot of noise levels and number of roads merging at traffic intersections as four (1) and three (2) is presented in Figure 4a. It can be seen that, as compared with three roads merging at intersections, four roads merging had elevated noise levels. Vehicular traffic from these streets contributes to noise levels at these intersections. Similar observations were also recorded for the presence of traffic light (1) and absence of traffic light (2) (Figure 4b). Traffic light controlled intersections leads to decelerating and accelerating traffic resulted in higher noise levels than free-flowing traffic without traffic light because of higher engine noise levels and unnecessary honking. Traffic volume high (1), medium (2) and light (3) contribution to noise levels are depicted in Figure 4c. A clear distinction in noise level was observed between these three types of traffic volume with maximum in heavy and the minimum in light.

The results reported by Leong (2003) for maximum daytime and nighttime noise level of Bangkok streets were comparatively lower than those obtained from the study area. As reported by Djercan et al. (2015) noise intensity was in strong positive correlation with number of vehicles in traffic is in agreement with the results reported in this study.

Vijay et al. (2013) reported no correlation between traffic volume and observed noise levels. The results of the study were in agreement with this observation. Coensel et al. (2006) found intersection type had a small influence on noise emissions. Results of the study corroborate with these findings. Traffic intersections with three or four roads merging into it had no significant influence on traffic noise level.

According to Ressel (2007) intersection with traffic light had higher noise level than roundabout and intersection with traffic light turned off. At Janata college square (with traffic light) the result reported was in unity. Roundabout with traffic lights at Ramnagar police station square and Bangali camp square had comparable results for noise levels during 24-hours with 87.30 dB(A) and 88.85 dB(A) respectively. Due to heterogenic traffic volume and activities at intersections like honking, ideal, gear noise, bearing noise, breaking noise, tyre-road noise and exhaust noise Vijay et al. (2013) may have contributed to these elevated noise levels. In case of Warora naka square traffic lights were not installed led to fluid continuous flow traffic typology. In addition, over bridge which carried heavy traffic (trucks and buses) had resulted in noisiest traffic intersection from the study area with 24-hours noise level of 91.14 dB(A).

As reported by Dzambas et al. (2014) and Nelson (1987) advantage of roundabout and intersection without traffic light was decreased in traffic noise level. These observations were recorded at Gandhi square were 24-hours noise level was 84.73 dB(A). This intersection was located in the heart of the city with congested streets and one-way traffic flow. In spite of these situations, 24-hours noise level (Ldn) was one of the lowest from the nine intersections studied. The reason can be attributed to mini-roundabout and absence of traffic light which allows all type of traffic volume always on move with a comparatively steady velocity although with reduced speed.

Crossing resulted by traffic light had higher noise levels due to decelerating and accelerating traffic because of higher engine noise (Dzambas et al., 2014) was observed at Janata college square, Priyadarshani square, and Girnar square. Average noise level at daytime and nighttime at ten important intersections of Agartala city was 79.9 dB(A) and 73.3 dB(A) respectively (Pal and Sarkar, 2013) which was comparatively lower as compared with study area (81.55 dB(A) for daytime and 77.83 dB(A) for nighttime). (Pal and Sarkar, 2013) further reported, when vehicles were waiting for their turn to clear the intersection, drivers normally keep vehicle engine running and unnecessarily blow the horn. These observations were recorded from the study area also.

Tsukui and Oshino (2001) report noise level close to the signalized intersection was 2.4 dB(A) higher than fluid continuous traffic flow typology. This observation was in agreement with results obtained from the study area, with average 1.31 dB(A) higher noise levels as compared with Janata college square (traffic light intersection) versus Jatpura gate and Bagla square (without traffic light intersection). The roundabout induces to a 2.5 dB(A) noise reduction compared to signalized intersection in an undersaturated traffic flow regime (Chevallier et al., 2009). This finding was observed in the study area also. It was observed that the noise level during 24-hours between Gandhi square (mini-roundabout) and Janata college square (traffic light presence) was less by 1.14 dB(A).

Active adaptation of traffic light cycles to the vehicle speed, so that a vehicle should not decelerate or accelerate in correspondence of the intersection, can lead to decrease up to 2 dB(A) in the noise equivalent level (Map of consolidation measures of road noise as OPB art, 1998). Adaptation of this method in the noisiest traffic intersection can contribute to noise level reduction. Noise level was closely related to the number and composition of road traffic (Manea et al., 2017). The results obtained for this study were not in agreement with these findings.

Street traffic noise in Yazd city, Iran was in the range of 70.9 dB(A)-80.7 dB(A) (Nejadkoorki et al., 2010). Results obtained from the study area for 24-hours (Ldn) were slightly higher (84.34 dB(A)-91.14 dB(A)). A significant relationship (R^2=0.5) between the average sound level and traffic flow was demonstrated (Nejadkoorki et al., 2010). These findings were in agreement with the results obtained from the study area (r=-0.623, $p<0.05$). Dwellings near the street of Yazd city were likely to be exposed to unacceptable levels of noise (Nejadkoorki et al., 2010). Shopkeepers and police personnel from the study area had reported annoyance, lack of concentration, sleep disturbance and stress due to exposure to street traffic noise.

3.7 Noise Pollution Control Measures

Noise is a major factor that should be considered in the design and construction of a new transport system, as well as when improvements are to be made in existing systems (Abo-Qudais and Alhiary, 2007). Landscaping and proper engineering planning at traffic intersections will contribute to noise reduction. In addition, traffic management will be a potential option to mitigate noise levels by implementing proper vehicular movements to avoid traffic congestions and hence a reduction in noise pollution associated with it. Necessary modifications in vehicular engine and silencer can contribute significantly to the reduction of noise level at the source itself. Use of low noise silencer and proper horn level can attenuate noise level. Removal of encroachment, creation of parking lots and proper road construction particularly near the silence zones will help to reduce noise level. Furthermore, different strategies can be adapted to control noise levels at a traffic intersection includes: extending use of high occupancy vehicles for public transport, curbing motorized traffic and blowing of horn, encouraging non-motorized modes, turning off vehicle engines at traffic lights, and imparting traffic education (Pal and Sarkar, 2013). Infrastructure up-gradation for intersections and roads, traffic flow management, avenue plantation and construction of sound barriers (Balashanmugam et al., 2013) can also contribute to vehicular noise pollution reduction.

4. CONCLUSIONS

Traffic intersections have emerged as one of the major sources contributing to noise pollution. Spatio-temporal noise levels variations at these intersections were governed by factors such as traffic type, traffic light presence, traffic flow, number of roads merging at intersections and roundabouts. Noise exposure to inhabitants and traffic personnel deployed at these intersections was high and correlated with daytime noise levels. Noise levels at these intersections were escalating at a very fast rate and were found to be above the Indian standards for the commercial area during daytime. Daily noise exposure and exposure points were directly related to duration of noise exposure (in hours) at these intersections. Although, no immediate damage risk for hearing loss on inhabitants and traffic personnel was arrived at; however, effective noise management is the need of the hour so as to reduce future health-related consequences due to it.

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